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Proposal for Development of the RT-21 Transmitter

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I. Introduction

Specification No. 58-A-1077-A enumerates the performance characteristics of the RT-21 Transmitter. It is understood that at the present time these requirements cannot be met. The purpose of the proposed activity is to develop circuitry and device techniques which will, by the conclusion of the program, lead to the realization of a prototype equipment satisfying the specifications. It is proposed to divide the program into three phases. Phase A will be a development phase during which techniques will be devised in order to achieve the desired circuit functions such as automatic frequency adjustment and antenna matching. At the conclusion of Phase A, the basic techniques will be available with which to perform the required functions although it may be that at that time, device limitations, in particular those of high frequency, high power transistors, will prevent complete satisfaction of the electrical specifications. During the course of Phase B a complete, integrated electrical design of the transmitter will be carried out, incorporating the techniques developed during Phase A. The design will be flexible being altered when and where necessary, to accommodate at all times the most advanced transistors from the stand point of frequency and power capabilities. At the conclusion of Phase B an operative transmitter will be delivered in ~~laboratory model~~ prototype form meeting the electrical specifications to the extent that available devices permit. Phase C will be concerned, primarily, with the final packaging of the equipment. At this stage, any electrical design changes or improvements deemed desirable will also be made. The objective of Phase C

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will be the realization and delivery of a complete transmitter prototype satisfying both the electrical and the mechanical requirements set forth in the previously mentioned Specification.

This proposal, while viewing the three phases as parts of a complete program, describes in some detail the technical approaches which will be made during Phase A. A detailed account of Phases B and C would be impractical until such time as the basic circuit techniques have been developed. It can be stated, however, that only those techniques compatible with the ultimate objectives of Phases B and C will be studied during Phase A.

The manpower estimates and funding which are included in this proposal are for Phases A and B only.

II. Technical Approach

As a result of recent work on a similar transmitter, many of the basic design problems have either been solved or the obstacles to their solutions clearly defined. Based on presently available circuit techniques the following additional requirements of the proposed transmitter present the greatest difficulty and will, consequently, call for the major share of the effort during Phase A.

1. Automatic tuning
2. Automatic antenna impedance matching

The problem of obtaining 10 watts at frequencies up to 30 mc with transistors is of course a major one. However, the limitation in this case is clearly one of devices. As stated in the Introduction, as improved transistors become available, they will be incorporated in the design.

(1) Automatically Variable Reactances

Both automatic tuning and impedance matching present many common problems. In particular, each requires the automatic adjustment of one or more reactive elements in order to produce a desired circuit condition.

(a) Mechanical

There are two basic approaches which can be taken. The first is the mechanical method suggested in the Specification, utilizing small servo motors to rotate relatively conventional variable capacitors and inductors. This method has been used for many years. Before it would be suitable for the present application, however, considerable effort will be necessary in order to reduce the physical size so that it would be compatible with the overall transmitter requirements. This work will include further development of miniature variable capacitors of the barium titanate and polyethylene types, similar

to those produced during the Radio Circuit Study. Work will also be done on novel "motor" mechanisms which would lend themselves to this application. The motion which is required to alter capacitance need not be rotational. Studies may show that a "motor" resulting in lateral displacement would be more desirable than a rotating device from a miniaturization and packaging standpoint.

(b) Electrical

The second approach to the problem of an automatically adjustable reactance is the electrical method in which there are no mechanically moving parts. This approach is novel and will call for the development of special solid state devices. This work will require the application of some of the improved materials which are becoming available in the form of ceramic dielectrics and ferrites.

(i) Electrically Variable Capacitors

An example of material which is available at the present time for the fabrication of electrically variable capacitors is a variety of barium titanate, the dielectric constant of which is strongly a function of the voltage impressed across the material. For a change of impressed voltage of 32 volts/mil. a change in dielectric constant from 6000 to 1200 is typical. One of the factors which has limited the application of material of this type is its temperature dependance. In a system of the type required for the RT-21 transmitter this problem is of considerably reduced significance. In both the tuning and impedance matching applications the effect of temperature would be that, for a given frequency or antenna configuration, the desired conditions would be obtained with a different voltage across the capacitor at different temperatures. This would be of no consequence as long as the range of variation was sufficient to accommodate all desired frequency and antenna configurations at all desired temperatures.

The amount of capacitance change obtainable is a function of temperature, exhibiting a peak around the Curie temperature. In order to broaden the temperature range over which a strong variation in dielectric constant can be obtained with applied voltage, two approaches are possible. The first approach is one of materials development. The second approach would be to use capacitors of several different materials, each peaking at a different temperature, connected in parallel.

A second problem associated with the use of voltage variable capacitors is that of isolation between the control voltage and the signal voltage. Using a capacitor of this type to tune the output tank of a vacuum tube transmitter is difficult due to the large voltage excursions of the signal frequency. If the control voltage is to be very large compared to the signal voltage, with vacuum tube stages, impractically high potentials are required. In the RT-21 transmitter operation is limited to transistors so that the signal voltage excursions will be very much reduced. This fact in combination with some of the isolation techniques proposed for vacuum tube circuits should result in a practical device. A method of isolation which has been considered relies on the geometry of the barium titanate. The signal and control voltages are applied to electrodes on different faces of the rectangular capacitor so that the bias field is at right angles to the signal field. The bias field is across the thin dimension so that its effect on the dielectric constant, being a function of volts/ mil., is greater than that of the signal which is applied across the thick dimension. Other techniques require the addition of a small component of the signal frequency shifted 90° in phase, to the control voltage. The control voltage can be generated by a dc-dc converter with little difficulty since no power is required, each capacitor representing essentially an open circuit.

(ii) Electrically Variable Inductors

Electrically variable inductors have been available in the form of saturable reactors for a long time. Their use in applications of the type required in the RT-21 transmitter has been impossible due to materials limitations. With the advent of ferrites and in particular the CQ series of high frequency ferrites the picture has been changed radically. The use of square loop materials provides the possibility of a new technique for automatic tuning.

During the first year of the Radio Circuit Study, work was done on a remote control system in which an attempt was made to control the frequency of an oscillator by varying the state of saturation of a square loop ferrite core in a number of discrete intervals. In this case accuracy of resettability precluded use of the system for its original purpose. In the RT-21 transmitter the steps of inductance change could be regarded as roughly analogous to band switching. The error signal could be used to activate a blocking oscillator which would pulse the core until the setting was approximately correct. The error signal would then be insufficient to cause the blocking oscillator to fire, the fine adjustment being by means of a voltage variable capacitor.

The advantage of using square loop materials for the variable inductors is that power does not have to be dissipated in order to maintain the inductance at its desired value since memory is inherent in the device. If high overall operating efficiency is important, as is invariably the case with battery-operated equipment, this feature is significant.

It is proposed to study both the electrical and mechanical methods of varying reactive components. The two approaches will be investigated simultaneously. The mechanical method is more likely to lead to successful results in a shorter time. However the electrical method is, from the overall standpoint, the more

desirable with probably superior miniaturization possibilities.

(2) Sensing Circuits

In the RT-21 transmitter two servo systems are required. The first will regard any condition other than resonance of the tuned circuits in the transmitter itself as constituting an error. The second will produce an error signal whenever the antenna is not matched to the transmitter output resistance. Circuitry must be devised to perform these functions.

(a) Resonance Sensing

A method which has been utilized with vacuum tube circuitry will be studied for possible application to the RT-21. The method relies on the fact that at resonance a tuned circuit appears purely resistive. Under these conditions the voltage at the grid of a tuned amplifier will be exactly out of phase with the voltage at the plate. When the plate tank circuit is other than resonant it will be reactive causing a phase shift other than 180°. This condition can be detected by a phase detector resulting in an error signal. An attempt will be made to obtain similar results using transistors. In the case of transistors, however, the problem is complicated by the fact that phase shift through the transistor will be a function of frequency to some extent. It may be necessary to have some compensation built into the phase detector so that the condition of balance changes with frequency.

At resonance the voltage swing developed across the tank circuit will be a maximum. A second approach will utilize this feature by comparing a small portion of the tank circuit voltage swing with a reference voltage from the untuned oscillator. By making the portion of the tank circuit voltage always smaller than that from the oscillator, even at resonance, and adding the two in such a manner that they are out of phase, resonance will be indicated by a mini-

mum resultant voltage. Essentially the same results could be obtained by rectifying a portion of the tank circuit voltage and comparing it with a reference dc voltage of opposite polarity.

(b) Impedance Match Sensing

One approach to the problem of sensing the condition of correct matching between antenna and transmitter utilizes a standing-wave bridge. The operation is as follows. It will be assumed that the output tank circuit has been adjusted for resonance either manually or by one of the techniques described above. The output of the transistor consequently appears to be purely resistive. This apparent resistance is arranged to form one arm of a bridge. Looking towards the antenna from the input of the impedance matching network, an impedance is seen which depends upon the antenna and the adjustment of the matching network. If the network was adjusted correctly for the particular antenna and frequency, the impedance seen would be resistive and equal to the apparent transmitter resistance. Consequently, by making this impedance the second arm of the bridge an output will be obtained for all conditions other than the desired one. This output or error signal may be used to adjust the reactances of the impedance bridge.

(3) Auxiliary Circuit Investigations

As a result of work recently completed the basic tools are available for the design of the remaining portions of the RT-21 transmitter. Experience has been obtained in the techniques for combining transistors to increase their output capabilities. The limiting factor for output power is the availability of a suitable device. As improved devices become available modified design techniques will be developed to utilize them to best advantage.

Depending upon the relative degrees of success of the different approaches to automatic transmitter adjustment described above a need will develop for the investigation of a large number of auxiliary circuits such as phase detectors, standing wave bridges, discriminators, dc amplifiers, blocking oscillators etc. The functions to be performed by these circuits are not new. The circuit designs will, however, have to be tailored to the particular requirements of the RT-21 so that they can be used to form an integrated piece of equipment.

III. Manpower Requirements and Time Schedule

1. Phase A. Circuit Development

This program will run for 12 months, during which time the following areas will be investigated.

Variable Reactances	(a)	Mechanical
	(b)	Electrical
Sensing Circuits	(a)	Resonance Sensing
	(b)	Impedance Match Sensing
Auxiliary Circuits		

Phase A will require the following engineering manpower

Engineers	125 man weeks
Technicians	75 man weeks

2. Phase B. Construction of the Electrical Model

At the conclusion of Phase A a period of 6 months will be spent in construction of an electrical model. This model will incorporate the most satisfactory methods developed during Phase A. Phase B will terminate with the delivery of a complete transmitter meeting the electrical requirements listed in the Specification to the extent that devices then available permit.

Phase B will require the following engineering manpower

Engineers	20 man weeks
Technicians	20 man weeks

Reports will be submitted in accordance with the Schedule given in Specification No. 58-A-1077-A.